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ABSTRACT

There are advantages to using a priori or planned comparisons rather than omnibus multivariate analysis of variance (MANOVA) tests followed by post hoc or a posteriori testing. A small heuristic data set is used to illustrate these advantages. An omnibus MANOVA test was performed on the data followed by a post hoc test (discriminant analysis). A second MANOVA using Helmert coding as a means for a planned comparison test was run and the results were compared to those from the MANOVA followed by the unplanned tests. The results provide concrete examples of the different possible outcomes using various procedures. Two advantages of using planned or a priori contrast over post hoc tests are presented. In addition to increasing the power against Type II error rate, planned comparisons force the researcher to be more thoughtful in the design of the research. Nine tables and an appendix containing the questionnaire. (Contains 24 references.) (Author)

The Advantages of Using Planned Comparisons Over Post Hoc Tests

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ABSTRACT

There are advantages to using a priori or planned comparisons rather than omnibus multivariate analysis of variance (MANOVA) tests followed by post hoc or a posteriori testing. A small heuristic data set is used to illustrate these advantages. An omnibus MANOVA test was performed on the data followed by a post hoc test (discriminant analysis). A second MANOVA using Helmert coding as a means for a planned comparison test was run and the results were compared to those from the MANOVA followed by the unplanned tests. The results provide concrete examples of the different possible outcomes using various procedures. Two advantages of using planned or a priori contrast over post hoc tests are presented. In addition to increasing the power against Type II error rate, planned comparisons force the researcher to be more thoughtful in the design of the research.

Researchers use a variety of analytical methods to evaluate the differences between means. However, there is considerable controversy surrounding the various methods. Bray and Maxwell (1985, p. 8) describe the controversy in two areas:

> 1) Issues concerning the overall test, such as choices between test statistics, power and sample size concerns, and measures of effect size, and 2) methods for further analyzing and interpreting group differences.

The most commonly used analytical techniques to find differences in means are analysis of variance methods: analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA), hereafter referred to as "OVA methods" (Thompson, 1985).

This paper will focus on the use of MANOVA, but the reader is encouraged to read Stevens (1990) for an explanation of the other OVA methods. The forerunner to MANOVA, univariate analysis of variance (ANOVA), developed in the 1920s by Fisher, has been used extensively in social science and experimental research

since its inception. MANOVA, on the other hand, had limited use when it was first conceptualized because of perceived computational complexity. Within the last two to three decades, however, MANOVA has been deemed more usable in experimental research, partly due to the accessibility of computer programming for MANOVA (Swaminathan, 1989).

Throughout the years, the popularity of all OVA methods has evidenced itself in research studies, although investigations of research trends indicate use of these methods has declined more recently. Edgington (1974) reported on APA journals from 1948 to 1962. Seventy-one percent of the articles that used inferential statistics utilized ANOVA procedures. Likewise, Willson (1980) found that from 1969-1978, OVA methods were used in 56 percent of the articles published in the *American Educational Research Journal* (AERJ). In 1985 Goodwin and Goodwin reported that 37 percent of the AERJ articles from 1979-1983 used OVA techniques, while Elmore and Woehike (1988) showed that ANOVA and ANCOVA methods made up 25 percent of the techniques used in articles published between 1978 and 1987. Daniel (1989, p.1) concluded, "Thus there is

some trend away from the use of OVA methods in educational research, although these methods are still used with considerable frequency."

Many researchers have criticized the use of OVA methods in recent years. For example, Cohen (1968, p. 441) describes the use of OVA methods as sometimes necessitating the "squandering [of] much information." Thompson (1986) explains that most OVA methods require all independent variables be nominally scaled, even though most are scaled higher. For example, an intervally scaled independent variable might be reduced to "low, medium, high," thus eliminating data and misrepresenting the reality underlying the data already collected (Daniel, 1989). Cohen (1968, p. 441) discusses the reduction of power against Type II errors resulting from decreased reliability levels of variables that were originally higher than nominally scaled.

Secondly, some researchers who have used OVA methods have thrown out cases to achieve proportionality or equal numbers of subjects in each cell. This type of "balanced" design provided less complicated computations at a time when computers were

not readily available. The situation is distorted when researchers eliminate subjects in order to achieve "balanced" cells (Cohen, 1968).

The debate over the proper use of analytical methods does not end once initial statistically significant differences among means are found. When using traditional applications of OVA methods, the researcher tests the omnibus OVA effects and, if a statistically significant difference is found, then the researcher needs to perform a follow-up test to locate where the statistically significant differences occur. Huck, Cormier, and Bounds (1974, pp. 87-88) explain:

> If the F corresponding to a main effect is significant, a researcher will know that there are significant difference among the overall means for the levels making up the factor. However, he will not know which specific levels are significantly different from one another. To answer this question, a researcher will need to apply a follow-up test.

However, there is controversy surrounding the choice of follow-up tests. Many "unplanned" or "post-hoc" tests

(also ca__ ɜd "aposteriori" tests) are available, including Scheffe, Tukey, or Duncan tests (Thompson, 1988). Following a MANOVA, discriminant analysis (which will be the focus of this paper) may be used in order to find out "which characteristics are most powerful discriminators" (Klecka, 1980, p. 9).

Post hoc comparisons usually entail performing numerous analyses involving all possible comparisons of means, even though this practice may not always be appropriate. Thompson (1990, p. 11) states:

> Some researchers always test even omnibus effects that are not of interest because they naively believe that such analyses always increase the probability of detecting statistically significant effects on the omnibus hypotheses that are of interest.

When a researcher performs comparisons of all means, several hypotheses are tested. When several hypotheses are tested within one study, there is an inflation of experimentwise Type I error rate, i.e., the possibility of making a Type I error somewhere in the study. Fish (1988) gives the calculations of "experimentwise" error rates for studies involving one sample of research

participants while varying the "testwise" alpha levels and the numbers of perfectly uncorrelated dependent variables. If a researcher conducts five tests, all at the .05 level (5% chance of making a Type I error), the probability of making a Type I error somewhere (anywhere) in the study does not remain at the .05 level. As proved by Love (1988), the experimentwise alpha rate actually may escalate as high as 0.226219 $[1 - (1 - .05)^5]$, indicating there is approximately a 23% chance of making a Type I error somewhere in the study. Hence, the experimentwise error rate may not equal the nominal testwise alpha level used with each separate hypothesis tested (Thompson, 1990). To avoid inflating experimentawise Type I error rate, certain statistical adjustments are incorporated in post hoc procedures. For example, Bonferroni corrections revise "testwise" alpha levels by dividing the nominal level by the number of tests (Fish, 1988). However, these adjustments decrease power against Type II errors, a trade-off that causes many researchers to use alternative analytical methods for comparing group means (DuRapau, 1988).

"Planned" (also called "a priori" or "focused")

comparisons have been recommended as a valuable alternative to post hoc tests. Planned comparisons can be orthogonal (which is the focus of this paper) or nonorthogonal. With orthogonal planned comparisons, decisions regarding the null hypothesis of one contrast are not influenced by the decisions regarding any other comparison (DuRapau, 1988).

One of the important advantages of planned comparisons is the protection they offer against Type II error. Kerlinger and Pedhazur (1973, p. 131) explain:

> The test of significance for a priori, or planned comparisons are more powerful than those for post hoc comparisons. In other words, it is possible for a specific comparison to be not significant when tested by post hoc methods but significant when tested by a priori methods.

Planned comparisons have a second and more important advantage. The planning involved in an a priori procedure forces the researcher to be more thoughtful in the design of the research (Thompson, 1988), basing analytic methods on the researcher's

sense of the relationships among the variables most worthy of study. A researcher must carefully scrutinize, ahead of time, the combinations of comparisons that will most likely contribute to and enhance the research effort.

PURPOSE

The purpose of the present paper is to demonstrate with concrete examples (a) the problems surrounding the use of post hoc procedures in MANOVA, and (b) the advantages of using planned comparisons. A small data set is used to illustrate the discussion.

METHODS

Subjects

Third grade teachers from 16 different schools in one Louisiana school district were involved in a science grant. The three year grant involves the collaborative efforts of the University of New Orleans and the Louisiana Nature and Science Center, to assist teachers in teaching science to students who learn differently. For the purposes of this paper two portions of data, teachers' responses to a modified version of a Concerns Questionnaire (Hall, George, &

Rutherford, 1977) and their scores on the life science portion of the National Assessment of Educational Progress (NAEP), were selected from an array of data. The modified Concerns Questionnaire measured the level of concern associated with the innovation. Twenty-four teachers were randomly assigned to three different groups, with each group containing eight teachers. Groups 1 and 2 were experimental groups and Group 3 acted as a control. Teachers in Group 1 received science training as well as training on a computer retrieval bulletin board system. Group 2 teachers received only the training on the bulletin board system. Group 3 teachers received no training.

Table 1 presents the data collected for each group. For heuristic value, the NAEP data for Group 2 were manipulated. Hence, no substantive interpretation of the results is intended, although the analyses do indicate the methodological issues mentioned previously. Case 122 actually received a score of 32 which was changed to 25. Likewise, Case 134's NAEP score was changed from 49 to 40.

Insert Table 1

about here

Procedures

At the beginning and end of the year the teachers were asked to complete the modified Concerns Questionnaire (see Appendix A for a copy of the questionnaire) and to answer the life science questions on the NAEP for ages 9, 13, and 17. Only the post year scores were included in the present study. To illustrate the potential problems of using post hoc procedures, a traditional MANOVA was run, testing the overall omnibus hypothesis of no difference between the means of the three groups. To further describe and explain differences, a discriminant analysis was then run as a post hoc procedure.

MANOVA results were then rerun using planned comparison tests. Variations in results when using the planned comparisons as opposed to post hoc procedures were noted. For the purposes of illustrating the planned comparison procedure, two Helmert contrasts (a

type of planned comparison) were performed. Helmert contrast are appropriate for "equal n, uncorrelated" contrasts. A Helmert contrast implies that statistical significance on one Hermert contrast in no way suggests statistical significance on the other contrast. As Stevens (1992, p. 219) explains the process, "To determine the unique contribution a given contrast is making we need to partial out its correlations with the other contrasts."

In the first contrast the average scores of the treatment groups (Groups 1 and 2) were compared to Group 3. In the second contrast, Groups 1 and 2 were compared. To run the correct comparisons, the researcher renamed the groups "GR" and switched the numbers assigned to Groups 1 and 3. Without switching the names the Helmert contrast would have used Group 1 as a control group and Groups 2 and 3 as treatment groups. It is important to note that when discussing the first MANOVA and the discriminant analysis, the word "Group" is used in reporting the results. Group 1 and 2 were the treatment groups and Group 3 was the control. When discussing the contrast procedure, the variable name "GR" is used for the grouping variable,

indicating that GR 1 was the control group and GR 2 and 3 are the two treatment groups. As indicated in Table 2, the outcome variable values did not change, only the numerical designation of the groups changed.

Insert Table 2

about here

RESULTS

The traditional MANOVA, post hoc discriminant analysis, and MANOVA with planned comparisons were run in SPSS. Table 3 reports the mean scores and standard deviations for all three groups on both dependent variables.

Insert Table 3

about here

Groups 1 and 2 answered the questions on the Concern Questionnaire in a similar manner, as evidenced by their mean scores (77.125, and 77.750,

respectively). Group 3's mean score was higher (82.6250). Group 2 had the largest variance about the mean (SD=14.089).

On the NAEP measure, Group 3 had the highest mean score (44.00), followed closely by Group 1 (43.625). Again, Group 2 had the lowest mean score (35.500) and highest variance about the mean (SD=7.309).

Results of Traditional MANOVA with Follow-up Discriminant Analysis

The results of the MANOVA indicate that there is no statistically significant difference between the means of Groups 1,2 and 3 (Wilks' lambda = .63558), although the p value of the calculated F (.054) is only slightly larger than the critical *p* of .05. Table 4 displays the results for several classic MANOVA tests of statistical significance.

Insert Table 4

about here

Since there was no statistically significant difference between groups, a post hoc test would not be

necessary; however, the researcher ran a discriminant analysis on the data to determine where the differences were among the groups. Those differences are understood by examining the discriminant functions (Heausler, 1987). Table 5 reports the canonical discriminant functions.

Insert Table 5

about here

The Wilks' lambda indicates that 36.44% of the variance is explained by both functions and that 4.35% of the variance in the groups is explained by Function II. Statistical significance was not found, even before Function I ($p = 0.0542$) was extracted.

Heausler (1987) emphasizes the importance of examining the structure coefficient matrix. The structure coefficients are the correlations of each of the dependent variables with each set of discriminating function scores. Table 6 displays the structure matrix.

Insert Tables 6

about here

The two dependent variables have absolute values that are dissimilar on Functions I and II. As indicated in Table 6, NAEP scores contributed most highly (structure coefficient = .998) to Function I, while scores on the Concern Questionnaire contributed most highly (structure coefficient = .99) to Function II. Both dependent variables contributed to the separation along both dimensions, with the dependent variables having opposite effects on Function II.

The group centroids (average discriminant scores of the subjects in a given group for a given function) are presented in Table 7. The centroids for Function I indicate that all three groups are somewhat different. Notice that Group 3 has the largest positive centroid. As stated earlier, the NAEP has a very high, positive structure coefficient on Function I. This would lead the researcher to expect somewhat higher scores on the NAEP for the people in Group 3. These results are

consistent with the cell means reported in Table 3. For Function II, Group 3 has the largest positive centroid. The Concern Questionnaire has a very high, positive structure coefficient on Function II. This would lead the researcher to expect higher scores on the Concern Questionnaire for the people in Group 3. Again, the results shown in Table 3 indicate a higher mean score on the Concern Questionnaire for Group 3.

Insert Table 7

about here

Results of MANOVA Using Planned Comparisons

As previously indicated, Helmert contrasts were utilized to perform the planned comparison tests. Table 8 displays the results of the first Helmert contrast and Table 9 reports the results of the second. The results of the first Helmert contrast indicate that the control group does not differ to a statistically significant degree from the average of the two treatment groups on the set of two variables ($p > .05$). However, the results of the second Helmert contrast

indicate that the two treatment groups differ to a statistically significant degree ($p < .05$) on the set of two outcome variables.

Insert Tables 8 and 9

about here

DISCUSSION

Based on the results of the overall MANOVA, the omnibus test was not statistically significant. Therefore the null hypothesis of equality among all means was not rejected. In traditional practice, post hoc tests would not be conducted following a non-statistically significant result; however, for the purposes of comparing these initial results with the planned comparison tests to follow, a post hoc discriminat analysis was conducted. The results of the discriminant analysis added more distinguishing information about the groups, but also indicated no statistically significant differences. In performing the two Helmert contrasts, the results changed for one of the contrast. Statistical significance was found in

the difference between the treatment groups, but not in the contrast between the control group and the combination of the treatment groups.

If statistical significance were used as the criteria for meaningful results, the researcher would draw different conclusions if a post hoc test were used rather than a planned comparison test. Thus, "Planned" or "a priori" tests have important advantages over "unplanned" or "post hoc" tests. These procedures provide greater statistical power against Type II error, and help locate specific sources of variance. Planned comparisons also force the researcher to think about the relationships among groups in advance.

For example, in this study the researcher planned to statistically test the most logical comparisons. When comparing the control group to the treatment groups, the researcher attempted to maximize the opportunity to show differences between those groups receiving some innovation and the group receiving none. In the second contrast the researcher focused on the differences between the two innovations. A "blind" post hoc analysis could test all comparisons, but the researcher only questioned the differences between the

presence and absence of an innovation and the differences among innovations.

The results with the heuristic data support Sowell and Casey's (1982, p. 119) thesis, "planned comparisons are the most powerful comparison tests available." Sowell and Casey go on to state that none of the post hoc procedures "has the power of planned comparison tests for detecting statistical significance." Consequently, as Benton (1989) and Tucker (1991) suggest, researchers and the research effort would benefit from more frequent use of planned comparison tests.

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TABLE 1: PRESENTATION OF DATA

CASE	GROUP	CONCERN	NAEP
101	1	70	45
105	1	78	43
106	1	90	50
116	1	80	35
107	1	67	53
102	1	68	44
109	1	71	41
120	1	93	38
122	2	52	25
104	2	77	25
121	2	82	25
134	2	62	40
138	2	90	25
144	2	94	44
145	2	83	41
44	2	82	39
164	3	81	45
162	3	80	44
163	3	84	41
166	3	89	41
171	3	86	50
190	3	90	40
64	3	64	50
61	3	87	41

TABLE 2: CORRECTED PRESENTATION OF DATA FOR CONTRASTS

CASE	GROUP	CONCERN	NAEP	GR
101	1	70	45	3.00
105	1	78	43	3.00
106	1	90	50	3.00
116	1	80	35	3.00
107	1	67	53	3.00
102	1	68	44	3.00
109	1	71	41	3.00
120	1	93	38	3.00
122	2	52	25	2.00
104	2	77	25	2.00
121	2	82	25	2.00
134	2	62	40	2.00
138	2	90	25	2.00
144	2	94	44	2.00
145	2	83	41	2.00
44	2	82	39	2.00
164	3	81	45	1.00
162	3	80	44	1.00
163	3	84	41	1.00
166	3	89	41	1.00
171	3	86	50	1.00
190	3	90	40	1.00
64	3	64	50	1.00
61	3	87	41	1.00

TABLE 3: MEANS FOR CONCERN QUESTIONNAIRE AND NAEP

CONCERN	GROUP	MEAN	SD
	1	77.125	10.006
	2	77.750	14.089
	3	82.625	8.314
NAEP	1	43.625	5.902
	2	35.500	7.309
	3	44.000	4.071

TABLE 4: MULTIVARIATE TESTS OF SIGNIFICANCE FOR EFFECT GROUP

Test Name	Value	Appox. F	Hypoth.DF	ErrorDF	Sig.of F
Pillai's	.37902	2.45514	4.0	42.00	.060
Hotelling's	.55041	2.61445	4.0	38.00	.050
Wilks'	.63558	2.54343	4.0	40.00	.054
Roys	.33551				

TABLE 5: STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2
CONCERN	0.06624	1.00173
NAEP	0.99197	-0.15445

TABLE 6: STRUCTURE MATRIX

	FUNC 1	FUNC 2
NAEP	0.99782*	-0.06599
CONCERN	0.15384	0.98810*

TABLE 7: CANONICAL DISCRIMINATE FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CENTROIDS)

GROUP	FUNC 1	FUNC 2
1	0.42127	-0.25222
2	-0.93838	0.01661
3	0.51711	0.23561

TABLE 8: MULTIVARIATE TESTS OF SIGNIFICANCE FOR HELMERT CONTRAST 2

Test Name	Value	Appox. F	Hypoth.DF	ErrorDF	Sig.of F
Pillai's	.26788	3.65890	2.0	20.00	.044
Hotelling's	.36589	3.65890	2.0	20.00	.044
Wilks'	.73212	3.65890	2.0	20.00	.044
Roys	.26788				

TABLE 9: MULTIVARIATE TESTS OF SIGNIFICANCE FOR HELMERT CONTRAST 1

Test Name	Value	Appox. F	Hypoth.DF	ErrorDF	Sig.of F
Pillai's	.15578	1.84520	2.0	20.00	.184
Hotelling's	.18452	1.84520	2.0	20.00	.184
Wilks'	.84422	1.84520	2.0	20.00	.184
Roys	.15578				

Appendix A

CONCERNS QUESTIONNAIRE

	NOT TRUE OF ME NOW	SOMEWHAT TRUE OF ME NOW	VERY TRUE OF ME NOW
1. I have very limited knowledge about the innovation.	○○○	○○○	○○
2. I am concerned about not having enough time to organize myself each day.	○○○	○○○	○○
3. I now know of some other approaches that might work better.	○○○	○○○	○○
4. I would like to help other faculty in their use of the innovation.	○○○	○○○	○○
5. I am concerned about how the innovation affects students.	○○○	○○○	○○
6. I am not concerned about this innovation.	○○○	○○○	○○
7. I would like to know who will make the decisions about the innovation.	○○○	○○○	○○
8. I would like to know what resources are available if we decide to adopt this innovation.	○○○	○○○	○○
9. I am concerned about my inability to manage all the innovation requirements.	○○○	○○○	○○
10. I am concerned about evaluating the impact of the innovation on students.	○○○	○○○	○○
11. I would like to revise the innovation's instructional approach.	○○○	○○○	○○
12. I am completely occupied with other things.	○○○	○○○	○○
13. I would like to excite my students about their part in this approach.	○○○	○○○	○○
14. I would like to know what the use of the innovation will require in the immediate future.	○○○	○○○	○○
15. I would like to coordinate my effort with others to maximize the innovation's effects.	○○○	○○○	○○
16. I would like to have more information on time and energy commitments required by the innovation.	○○○	○○○	○○